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by

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SUMMARY

In cooperation with the Ontario Ministry of Natural Resources, selected deposits of Potsdam sandstone in the Ottawa-Kingston area were core drilled and the core evaluated by CANMET as potential glass and foundry sand. Core analyses ranged from 84.6 to 98.5% SiO_2, 0.09 to 0.65% Fe_2O_3, and 0.07 to 2.10% Al_2O_3. The core were largely composed of white to grey, relatively tough sandstone. Impurities included iron as pyrite, and as iron oxides and staining on the quartz grains; carbonates as calcite; and aluminium oxide as feldspar. Beneficiation included size reduction to grain size, about 600 µm, by jaw, roll and cone crushers, and grinding in a muller-mixer. Removal of fines was achieved by attrition scrubbing and washing. Further removal of impurities was achieved by reverse flotation of pyrite, iron oxide, feldspar, and carbonate minerals employing both anionic and cationic collectors. Flotation resulted in a substantial improvement in the quality of most samples, the quartz concentrates analysing 98.5 to 99.7% SiO_2, 0.022 to 0.156% Fe_2O_3, and 0.07 to 0.62% Al_2O_3. Further reduction of the iron content by wet magnetic separation and acid leaching also was investigated. On the basis of the samples submitted, sandstones from six of the seven deposits studied have potential as sources of glass sand. Foundry sand tests were inconclusive because of the limited quantity of sample available for study.

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RESSOURCES DU CANADA EN SILICE: ÉTUDE DU TRAITEMENT DES GRÈS DE POTSDAM EN ONTARIO, UTILISÉS DANS LA FABRICATION DU VERRE ET COMME SABLES DE FONDERIE

par

R.K. Collings* et P.R.A. Andrews**

RÉSUMÉ

En coopération avec le ministère des Ressources naturelles de l'Ontario, on a recueilli des carottes de sondage dans des couches sélectionnées de grès de Potsdam, dans la région d'Ottawa-Kingston; le CANMET a évalué les carottes de forage, pour voir dans quelle mesure on pouvait utiliser les grès dans la fabrication du verre et comme sables de fonderie. L'analyse a indiqué 84,6 à 98,5% de SiO_2, 0,09 à 0,65% de Fe_2O_3, et 0,07 à 2,10% de Al_2O_3. Les carottes étaient largement composées de grès blanc à gris, relativement dur. Parmi les impuretés, on a noté le fer sous forme de pyrite, d'oxydes de fer, et de macules sur les grains de quartz; les carbonates sous forme de calcite; et l'oxyde d'aluminium sous forme de feldspath. L'enrichissement consistait à fractionner le matériau jusqu'à 600 µm au moyen de concasseurs à machoîres, à meules et à cônes, et à le broyer dns un malaxeur. On a éliminé les fines par lavage et attrition. On a éliminé les autres impuretés, par flottation inverse de la pyrite, des oxydes de fer, du feldspath et des minéraux carbonatés, en employant des collecteurs anioniques et cationiques. La flottation a permis d'améliorer substantiellement la qualité de la plupart des échantillons; les concentrés de quartz contenaient, d'après l'analyse, 98,5 à 99,7% de SiO_2, 0,022 à 0,156% de Fe_2O_3 et 0,07 à 0,62% de Al_2O_3. On a aussi étudié la possibilité de réduire davantage la teneur en fer par séparation magnétique humide et lixivation à l'acide, D'après l'étude des échantillons examinés, les grès de six des gîtes étudiés sur sept pourraient fournir du sable utilisable dans la fabrication du verre. Les essais relatifs aux sables de fonderie ont été peu concluants, en raison du peu d'échantillons dont on disposait pour la réalisation de l'étude.

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INTRODUCTION

Canada continues to import significant quantities of high-purity sand, chiefly from the United States, for use in glass manufacture and by the foundry industry. Imports in 1981, for example, were 1.14 Mt valued at $18.5 million[1].

There are a number of potential sources of high-purity silica sand in Canada. This fact and the need for further study was highlighted at the Federal-Provincial Industrial Minerals Seminar that was held in 1980 in Ottawa[2]. Discussions within CANMET following that meeting resulted in a decision to initiate a laboratory study and appraisal of the technical feasibility of producing silica sand for glass and foundry applications from a few of the more attractive deposits for domestic consumption and export. Glass sand specifications usually stipulate that all sand should be between 600 and 100 μm in size, and have the following minimal chemical analyses - 99.6% SiO_2, 0.03% Fe_2O_3, 0.15% Al_2O_3, with low lime and magnesia. Iron and steel foundry sands vary in grain size between 850 and 75 μm in closely sized ranges. AFS (American Foundryman's Society) numbers vary between 55 and 65, with the bulk of the sand preferably being on three adjacent sieves. A rounded grain shape is preferred. The quartz content should be high, 99% SiO_2, with low aluminum, iron, sodium and potassium oxides, the last three acting as fluxing agents.

This 3-year study would be made in cooperation with the provincial governments and was to concentrate initially on Ontario, the chief consuming province and, later, on selected resources in several of the remaining provinces. This report outlines work undertaken on Ontario Potsdam sandstone during 1982/83. The Ontario Ministry of Natural Resources co-operated fully in this work; Dr. Mike A. Klugman of OMNR was of invaluable assistance in this regard.

SOURCE AND DESCRIPTION OF SAMPLES

An initial review was made of two reports of Ontario sandstone, open file reports 5265 and 5305 of the Ontario Ministry of Natural Resources[3,4]. On the basis of this review, Potsdam sandstone deposits in five areas were selected for detailed study. Drill core samples from single holes in each are briefly described in Table 1. These areas and

those highlighted in the noted reports were generally included in the area bounded by Ottawa, Arnprior, Kingston and Brockville as shown in Figure 1.

The selection of these particular deposits was based on the assumption that our study should include a range of purity of sandstones to determine the effectiveness of developed methods of processing and beneficiation to glass sand purity. Thus sample F-D, Table 1, with the highest silica content, 99.24%, also had a relatively low iron oxide content, 0.09%, but a higher alumina content, 0.61%, than sample Le-C. Sample Le-E, with the lowest silica content, 93.3%, also has the highest iron oxide, 0.47%, and alumina, 2.75%, contents. Drill core samples from their five holes were not available; however, the Ontario Ministry of Natural Resources obligingly drilled a new set of five holes in essentially the same general areas and shipped the core to Ottawa for study. Samples from two other deposits, both under investigation by potential producers, also were included in our study. Locations of the seven sample areas, identified as A to G, are noted in Table 2 and on the map, Figure 1.

PRELIMINARY STUDY OF SANDSTONE REDUCTION

In processing sandstone to sand for glass and foundry applications it is important that the parent sandstone is reduced to its natural grain size to free impurities for subsequent removal and, as well, that this be done without excessive fracturing of grains and resulting production of unwanted fines. Whole, unfractured grains are preferred in foundry moulding and fines are detrimental in both applications.

Preliminary reduction is easily achieved by jaw, cone, and roll crushers. Final reduction, to grain size, may be accomplished using one of several types of crushers/grinders, e.g., ring-roll, roller, ball or rod mills. Although normally performed dry, reduction of sandstone to grain size also may be accomplished by wet processing. Preliminary crushing/grinding studies were made using Potsdam sandstone samples from the Bells Corners area, west of Ottawa. Initial reduction, to 5 mm, was by a Blake jaw crusher with a 75 x 150 mm opening and, to 1.5 mm, by a 250 mm diameter Mine and Smelter cone crusher. Tertiary crushing, to 600 µm, was by a 125 x 200 mm double-roll, Sturtevant crusher. Further reduction to grain size was studied both dry and wet (98% solids) in a 450 mm diameter Simpson muller-mixer. An examination of the crushed products showed a good

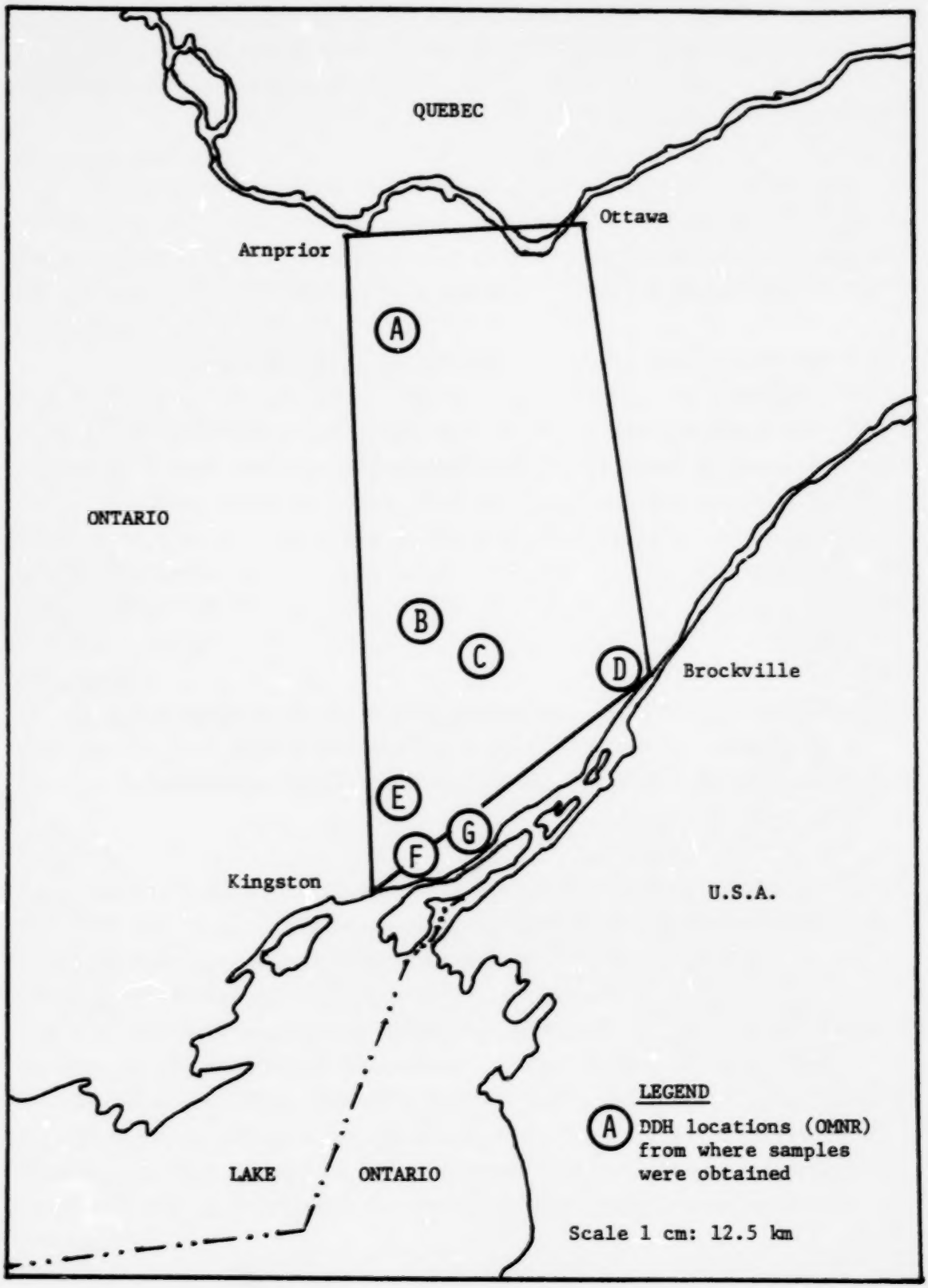

Fig. 1 - Location of seven sandstone sample sites

reduction of the sandstone to grain size with a minimum percentage of agglomerate and fractured grains.

Based on this initial study, the following 7-step procedure was adopted in processing the samples selected for study to ensure a maximum recovery of agglomerate-free sand with a minimum of overcrushing and resulting production of waste fines -

1. Stage crush to 5 mm by jaw crusher, removing minus 5 mm by screening following each pass.

2. Remove minus 600 µm sand from jaw crusher product by Sweco screen.

3. Stage crush minus 5 mm, plus 600 µm from jaw to 1.5 mm by cone crusher, removing minus 1.5 mm following each pass.

4. Remove minus 600 µm from cone product by Sweco screen.

5. Crush minus 1.5 mm, plus 600 µm from cone to minus 600 µm by roll crusher.

6. Combine all products and screen on Sweco at 125 µm.

7. Wet grind (98% solids) plus 125 µm product from Sweco to sand size in the Simpson muller mixer.

SAMPLE PREPARATION AND PROCESSING

The core samples were carefully examined to determine grain fineness, friability, impurities such as pyrite, iron staining, lime, etc. and to select an appropriate interval of core for study. The results are noted in Table 3.

Crushing/grinding

Following examination of the core, the selected samples were separately processed through the jaw, cone and roll crushers, sized by Sweco screen at 125 µm, and the plus 125 µm product wet-ground at 98%

solids for a 30-min. period in the Simpson muller-mixer. This scrubbing/grinding action reduced most of the compound grains to grain size without creating excessive fines.

Attrition scrubbing

Previous CANMET studies of the processing of sandstone-derived sand demonstrated attrition scrubbing to be an ideal secondary processing step. The intensive scrubbing aids breakdown of clay-bonded compound grains and the removal of coatings and surface staining on the individual quartz particles.

The muller-mixer product was scrubbed in a 10 kg capacity, Wemco attrition machine at 80% solids over a 20-min. period. The scrubbed product was water-washed for 5 min. and the solids settled during an additional 10 min. period. The slimes were then decanted at 100 µm and the entire procedure repeated. Three washing-settling-decanting cycles were required to free and remove the slimes. Sieve analyses of the washed attrition products are noted in Table 4, and the results of a binocular examination of the various products in Table 5.

Mineralogy

Representative portions of each sample were mounted in petrographic thin sections for examination and, as well, pulverized for analyses by X-ray diffraction using a Guinier camera. Results are recorded in Table 6.

Flotation

Removal of small quantities of liberated impurities by flotation is an efficient method of benefication. Because silica is the major constituent it is logical to float the impurities by reverse flotation leaving a pure quartz concentrate.

The procedure adopted for removal of impurites was based on the known response of the minerals to flotation. In this respect pyrite is best floated using xanthates, graphite using kerosene, and calcite using oleic acid. Flotation practice has previously demonstrated[5] that iron oxides and feldspar are best floated by first using petroleum sulphonate collectors to float iron oxides followed by cationic flotation using amines to float feldspar.

Previous cationic flotation studies on feldspar have always been conducted using HF as an activator for feldspar. Since HF is hazardous it was decided to try to float feldspar using standard amine collectors without HF. In addition, the collector Duomeen TDO (n-tallow-1, 3-diaminopropane dioleate) was used, since it is selective for feldspar[6]. Based on the above the following general procedure was adopted:

Stage 1. Graphite flotation using Kerosene at pH 9.

Stage 2. Sulphide flotation using Ethyl Xanthate at pH 6.

Stage 3. Calcite flotation using an Oleic Acid/Kerosene mixture at pH 7.

Stage 4. Iron Oxide flotation using Aerofloat 840 (natural petroleum sulphonate)[7] at pH 3.5-5.0, employing high pulp density conditioning(≈50% solids).

Stage 5. Feldspar flotation using Armac T (tallow amine acetate)[8], Armac C (coco amine acetate) at pH 2.3 to 3.5 and Duomeen TDO (n-tallow-1, 3-diaminopropane dioleate), at pH 2.1 to 2.8, employing high pulp density conditioning (≈50% solids).

Dowfroth 250 was used as frother where necessary in the majority of tests; MIBC frother was used in a few tests.

The outlined procedure was used only as a guide. The sequence of Stage 4 preceding Stage 5 was only used in the later tests. During the earlier part of the testwork experimentation was conducted with the single collector system, that is, either Aerofloat 840 or one of the feldspar collectors were used to float both iron oxides and feldspar.

After calcite flotation, the remaining quartz concentrate was filtered and washed twice to remove residual flotation reagents before repulping and conditioning at 50% solids. After conditioning the pulp density was diluted to ≈30% solids and flotation conducted without further conditioning.

Following completion of the final flotation stage all products were filtered and dried. Since only very small quantities of mineral were sometimes floated, it was decided to analyse only the quartz concentrates with the exception of certain selected floated products which were analysed for Al_2O_3 and Fe_2O_3. The resulting concentrate analysis, when compared to the flotation feed analysis, provided a good indication of the degree of success obtained in removing the impurities.

The complete analysis values for all tests are reported in Table 7, the corresponding reagent consumption values in Table 8, the conditioning and flotation times in Table 9, and the collectors employed in achieving optimum results in Table 10.

Magnetic separation

With the exception of sample C_T, the Fe_2O_3 levels were reduced to below 0.1% Fe_2O_3. For sample C_T, flotation was only able to reduce the level from 0.28% to 0.107% Fe_2O_3. The flotation concentrate of sample C_T was treated in a high-intensity Sala wet magnetic separator to determine whether a further reduction of the iron was feasible.

Acid leaching

To determine whether the iron oxide content of the quartz concentrates could be further reduced, several selected concentrate samples were acid leached at two sulphuric acid concentration levels - 20% w/v H_2SO_4 at 50°C for 6 h and 35% w/v H_2SO_4 at 70°C for 6 h.

Foundry sand testing

Samples of the scrubbed attrition products were submitted to the sand laboratory for evaluation as foundry sand. The small size of samples permitted only a very limited study. An initial size analysis of each sample was made, the fractions examined, and the AFS numbers determined. Moulding tests were performed using 2 kg of sand and the required amounts of bentonite and cereal. Moisture content, moulding characteristics, permeability, and green compressive and tensile strengths were determined. Results are reported in Table 11.

RESULTS AND EVALUATION

Crushing, grinding, scrubbing

Examinations of products from each stage of crushing and of the sized fractions from the Wemco attrition scrubber indicated that the various stages of size reduction satisfactorily reduced this sandstone to grain size without excessive fracturing of grains and production of unwanted waste fines. Product recoveries are noted in Table 12. Recovery of -600 + 100 µm sand from the attrition scrubber averaged 86.5% for the samples studied, and ranged from 75% for sample F to 95% for sample E. Most samples had a fairly uniform grain size with the bulk of the material being in the -600 + 150 µm range; sample A was more finely divided than the others. The products generally had relatively small percentages of compound and fractured grains; however, grain angularity or sharpness showed a substantial increase in the finer, -100 µm sizes. Sample F contained a substantial portion of sharply angular grains due to numerous inclusions of pockets or intersections of vein quartz in the drill core.

Most sands were white to light grey in colour, however, sample E was light brown due to a thin brown coating on the individual quartz grains. Impurities mostly consisted of pyrite, which was both free and firmly attached to quartz grains, iron staining, scattered dark mineral grains, and carbonate. Carbonate content varied quite widely from sample to sample. Sample G was distinctly different to the others in that it contained a significant portion of graphite as small specks adhering to the individual quartz particles.

Flotation

In general flotation successfully reduced iron oxide and feldspar to levels acceptable for the glass industry as the results in Table 7 show. Visual examination of flotation products also showed that pyrite and calcite responded well to flotation. For convenience and ease of observation, the analysis values for the best test obtained with each sample are summarized as follows.

Sample Identification	Analysis (wt %)				
	SiO_2	Fe_2O_3	Al_2O_3	CaO	LOI
A	99.50	0.024	0.089	0.050	0.27
B	99.59	0.029	0.077	0.055	0.13
C_T	98.82	0.107	0.363	0.104	0.20
C_B	99.54	0.030	0.067	0.063	0.15
D	99.16	0.044	0.433	0.089	0.15
E	99.65	0.034	0.089	0.017	0.10
F	99.40	0.037	0.074	0.043	0.21
G	99.11	0.043	0.098	0.039	0.28

All samples except C_T, produced quartz concentrates analyzing 0.024 to 0.044% Fe_2O_3, which is within range of the 0.03% Fe_2O_3 specification for glass sand. With regard to feldspar reduction, the Al_2O_3 level was reduced for all samples, except C_T and D, to between 0.067 and 0.098% Al_2O_3 which is below the 0.15% Al_2O_3 specification for glass sand.

A brief evaluation of the flotation behaviour of each sample is reported as follows:

Sample A

Quartz concentrates were successfully produced from all tests, analyzing 0.022 to 0.026% Fe_2O_3 and 0.089 to 0.098% Al_2O_3, using both amine collectors and Aerofloat 840. These levels could not be further reduced.

Sample B

This sample responded well to flotation, where quartz concentrates analyzing 0.028 to 0.038% Fe_2O_3 and 0.067 to 0.083% Al_2O_3 were obtained for Tests 15 to 17 and Tests 44 to 46, using both amine collectors and Aerofloat 840. The poor results of Test 14 indicate the necessity of introducing a separate calcite flotation stage. The quantity of oleic acid was varied but the resulting analyses suggest that there is little advantage in increasing the level beyond 0.42 kg/t.

Sample C_T

Flotation of iron oxides was reasonable but the resulting 0.107 to 0.144% Fe_2O_3 range is too high for glass quality sand. With the exception of Test 52 there was a poor response to feldspar flotation. A variation in the level of Armac T from 0.28 to 0.75 kg/t did not significantly decrease the percentage alumina of the quartz concentrates.

Sample C_B

Favourable results were obtained on all four tests. The alumina and iron oxide levels of the quartz concentrates were reduced to 0.067 to 0.078% Al_2O_3 and 0.030 to 0.041% Fe_2O_3 using both amine collectors and Aerofloat 840.

Sample D

Moderate success was obtained in reducing the iron oxide level to 0.044 to 0.067%. The response of feldspar to flotation, however, was only fair, using both the amine collectors and Aerofloat 840. The lowest alumina analysis obtained for quartz concentrates, 0.395% Al_2O_3, was still unacceptably high (Test 55). This value was obtained using a mixture of Armac C and kerosene.

Sample E

With this sample it was not necessary to conduct a separate calcite flotation since the calcite content was very low. The initial response to iron oxide/feldspar flotation by amine collectors was only fair as seen by the results of Tests 20 to 22. By using Aerofloat 840 alone and in combination with amine collectors (Tests 56 to 58), the alumina level was reduced to 0.089 to 0.096% Al_2O_3 and the iron oxide level to 0.033 to 0.039% Fe_2O_3. Even at these levels, however, the reddish brown colouration remained on the quartz particles.

Sample F

In Tests 37 and 38 where Aerofloat 840 and Duomeen TDO were used respectively, quartz concentrates were obtained where the iron oxide and feldspar levels had been successfully reduced to 0.031 to 0.037% Fe_2O_3 and 0.074 to 0.096% Al_2O_3. The alumina levels in the remaining tests were unacceptably high.

Sample G

Despite the fact that this sample was low in silica and discoloured due to the presence of graphite, it responded extremely well to flotation. The best test, Test 60, successfully produced a quartz concentrate analysing 0.043% Fe_2O_3 and 0.098% Al_2O_3 using Armac T as collector. The remaining tests gave analyses values ranging from 0.061 to 0.156% Fe_2O_3 and 0.181 to 0.336% Al_2O_3.

In the following discussion, reference is made to the point of zero charge (pzc) of the minerals floated in this investigation. While the pzc values were not measured for quartz, calcite and feldspar, reference is made to reported pzc values for the same minerals. It is considered that the reported values are representative of the pzc values of the minerals studied in this investigation.

Reported pzc values

Minerals	pzc values	Mean pzc values
Calcite[9,10]	10.8	10.8
Hematite[11]	5.0-6.7	5.9
Feldspar[12]	1.4-1.6	1.5
Quartz[13-18]	1.3-3.7	2.5

Calcite will float at pH 7 using oleic acid as collector since the calcite surface is positively charged below the pzc, the oleate ion being chemisorbed onto the calcite surface. During the testwork it was observed that quartz floated with the calcite when there was a high content of calcite in the sample feed (Samples B and G). While the reasons for this may be entrapment or cementious aggregates of quartz and calcite, there is the possibility of calcium activation. Clean quartz with no activator present does not float with oleic acid. In the presence of calcium ion, however, activation will occur. At a concentration of 100 mg/L calcium ion, Cooke and Digre[19] demonstrated that quartz will readily float after calcium activation at pH values as low as 8.6 and that partial flotation persisted down to pH 7.8. The presence of calcite is a source of soluble calcium.

Oleic acid will also float hematite at pH 7. While it is realized that the iron oxides have not been specifically identified, there is reason to suggest that oleic acid is floating the iron oxides to some degree, as the following results show:

Effect of oleic acid on iron oxide flotation

Test no.	Oleic acid kg/t	Calcite float % Fe_2O_3	Calcite float % Al_2O_3
15	0.42	0.38	0.20
25	0.39	0.64	4.61
35	0.38	1.83	1.06
40	0.76	1.23	1.78

These results also show that oleic acid floats feldspar to a limited degree; that feldspar can be floated to a limited extent using sodium oleate at pH 7 has been demonstrated by Gaudin[20].

Iron oxides are also floated by petroleum sulphonate collectors in the pH range 2 to 4. At this pH the surface charge is positive (pzc of hematite is 5.0 to 6.7) and thus responsive to anionic collectors. The following results, however, do not show that Aerofloat 840 (when used as the principal collector) was more selective towards iron oxides than Armac T or Duomeen TDO.

Effect of Aerofloat 840, Armac T and Duomeen TDO on iron oxide flotation

Sample no.	Test no.	Aero. 840*	Quartz Conc % Fe_2O_3	Test no.	Armac T*	Quartz Conc % Fe_2O_3	Test no.	Duomeen TDO*	Quartz Conc % Fe_2O_3
A	33	0.37	0.026	30	0.37	0.024	-	-	-
B	44	0.25	0.034	-	-	-	46	0.24	0.028
C_B	48	0.34	0.037	47	0.34	0.039	49	0.34	0.030
D	28	0.45	0.054	25	0.46	0.048	-	-	-
E	23	0.36	0.044	20	0.37	0.048	-	-	-
F	37	0.44	0.031	35	0.45	0.039	38	0.45	0.037
G	42	0.39	0.061	40	0.42	0.060	43	0.38	0.063

*Reagent concentration expressed as kg/t

When Aerofloat 840 precedes collectors such as Armac T and Duomeen TDO greater selectivity towards iron is apparent, as was reported in two tests. In Test 56, when using Sample E, a separate sulphonate float produced an iron oxide product analysing 9.71% Fe_2O_3 whereas the feldspar float produced a product analysing 0.89% Fe_2O_3. Similarly in Test 54, when using sample D, the sulphonate float analysed 1.14% Fe_2O_3 while the feldspar float analysed 0.23% Fe_2O_3. While it is realized that the lower iron oxide analyses for the feldspar floats correspond to a higher % weight of floated material than was obtained with the sulphonate floats, nonetheless a separate sulphonate float has improved the selectivity of these tests.

Cationic floation of feldspar in the majority of tests was conducted between pH 2.1 to 3.2. Examination of the pzc values for quartz and feldspar indicates that there is a narrow band between the mean calculated pzc values of both minerals. Within this pH band of 1.5 to 2.5 it is possible to float feldspar without floating quartz. Between pH 1.5 to 2.5 the surface charge of feldspar is negative while quartz, now being below its pzc, is positively charged and thus unresponsive to cationic collectors. The experimental results indicate that in the majority of tests this is true for quartz. The flotation response of feldspar is varied, the range of flotation response being from fair to good for all collectors. The response in some tests where Duomeen TDO was used showed that it was more selective than the other collectors for similar reagent concentrations, as the following results suggest.

Effect of Aerofloat 840, Armac T and Duomeen TDO on feldspar flotation

Sample no.	Test no.	Aero. 840*	Quartz Conc. % Al_2O_3	Test no.	Armac T*	Quartz Conc. % Al_2O_3	Test no.	Duomeen TDO*	Quartz Conc. % Al_2O_3
B	44	0.25	0.083	16	0.25	0.07	46	0.24	0.067
C_T	-	-	-	51	0.28	0.441	52	0.28	0.363
C_B	48	0.34	0.078	47	0.34	0.074	49	0.34	0.067
F	37	0.44	0.096	35	0.45	0.137	38	0.45	0.074
G	42	0.39	0.244	40	0.42	0.257	43	0.38	0.189

*Reagent concentration expressed as kg/t

The selectivity of the collectors employed in iron oxide and feldspar flotation is best illustrated by referring to Table 10, where the collector(s) employed to achieve the best test results are tabulated. This summary shows that Duomeen TDO was selective for floating feldspar in four samples. At higher concentrations (0.5 kg/t), Duomeen TDO floats excessive amounts of quartz as was witnessed in Tests 62 and 63.

Magnetic separation

Wet magnetic separation in the Sala high-intensity separator resulted in a significant reduction of the iron in sample C_T, from 0.133 to 0.064%; the following results were obtained using quartz flotation concentrates from Tests 18 and 19.

Test no.	Feed % Fe_2O_3	Mags % Fe_2O_3	Non-Mags % Fe_2O_3
18	0.14	0.50	0.065
19	0.14	0.41	0.063

These results show that the Fe_2O_3 has been successfully reduced to a level comparable to those obtained with the other samples by flotation alone. However, this value is still above the 0.03% Fe_2O_3 typically specified for glass sand.

Acid leaching

Acid leach test results, noted in Table 7, show significant reductions of the iron content of the flotation concentrates. The iron content of sample C_T , for example, was reduced from 0.140 to 0.061%, and of D, from 0.055 to 0.028%, by leaching. This latter value is acceptable for glass sand. Similar reductions were noted for Samples C_B, E, F and G.

Foundry evaluation

Although some of the processed sands may have potential as foundry sand, the small size of samples tested did not permit a full-scale evaluation.

CONCLUSION

On the basis of samples submitted, sandstones from six of the seven areas represented by these samples have potential as sources of glass sand, namely A, B, C_B, E, F, and G. Unfortunately C_B, representing the bottom 12.8 m of a 25 m drill hole, is overlain by C_T, representing the top 12.2 m. C_T did not meet glass sand specifications following beneficiation. Further research with larger and more representative samples is recommended to confirm the results of this preliminary study. Further research to more fully determine the potential of these sandstones as foundry sand also is recommended.

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Table I - Drill core samples, Ontario sandstone*

I-T

Drill hole identification	Formation and nature	Sample interval (metres)	Average chemical analysis (wt %)					Remarks
			SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	
F-B	Potsdam, sub-angular, calcareous	0 to 9.1	98.21	0.42	0.68	0.65	0.04	utilize top 9.1 m only, high iron, alumina, lime, (samples 4726 to 4728)
F-D	Potsdam, siliceous	0 to 9.3	99.24	0.09	0.61	0.02	0.04	utilize top 9.3 m only, high silica, alumina (samples 4733 to 4734)
L-D	March/Nepean, sub-angular to rounded, siliceous/ calcareous	0 to 20.1	96.82	0.84	0.99	2.00	0.11	utilize top 20.1 m only, low silica, high iron, alumina, lime (samples 4763 to 4767)
L_e-C	Potsdam, sub-angular to rounded, siliceous/ calcareous	0 to 15.2	98.65	0.09	0.25	0.99	0.03	utilize top 12.2 m only, high lime, (samples 4747 to 4749)
L_e-E	March, sub-round to round, siliceous/ calcareous	0 to 24.1	93.35	0.47	2.75	3.19	0.21	utilize top 24.1 m only, low silica, high iron, alumina, lime, magnesia, (samples 4790 to 4796)

* Ontario Ministry of Natural Resources, open file reports 5265 and 5305,[3],[4]

Table 2 - Drill core samples, identification and location

Identification	Location
A	Lanark county, Ramsay township, Concession IX, Lot 20, diamond drill hole L-F.
B	Leeds county, North Crosby township, Concession I, Lot 1, diamond drill hole Le-F.
C	Leeds county, Bastard township, Concession VII, Lot 26, W½, 27, E½, diamond drill hole A-S.
D	Leeds county, Elizabethtown township, Concession III, Lot 33, diamond drill hole Le-G.
E	Frontenac county, Storrington township, Concession VII, Lot 17, diamond drill hole F-G.
F	Frontenac county, Pittsburgh township, Concession III, Lot 20, diamond drill hole F-F.
G	Frontenac county, Pittsburgh township, Concession II, Lot 30, diamond drill hole C-C.

Table 3 - Drill core description

Sample			Description
A	whole core	-	0 to 10.4 m fine grain, white to brown, friable to tough, impure sandstone 9.1 to 10.4 m; 1.8 to 9.1 m intersection chosen for laboratory study.
B	whole core	-	0 to 8.8 m fine grain, white, friable sandstone; core loss about .6 m between 3.1 to 4.3 m; minor iron staining upper 3.1 m, white sandstone 3.1 to 7.6 m; hard limy sandstone with calcite veins 7.6 to 8.8 m; 0 to 7.6 m intersection chosen for laboratory study.
C_T	split core	-	0 to 12.2 m 0 to 0.9 m missing, possibly overburden; fine grain, white to grey, hard sandstone with minor iron staining and thin shaley seams or partings throughout; minor carbonate 9.1 to 12.2 m, 0.9 to 12.2 m intersection chosen for laboratory study.
C_B	split core	-	12.2 to 25 m fine grain, white to grey sandstone; minor iron staining, calcite, shale partings and quartz inclusions; 12.2 to 25.0 m intersection chosen for laboratory study.
D	whole core	-	0 to 6.9 m fine grain, white to grey and brown, tough sandstone; some iron staining, shale partings and calcareous sections; 0 to 6.9 m intersection chosen for laboratory study.
E	whole core	-	0 to 9.1 m fine grain, pink, relatively friable sandstone; minor inclusions of quartz with some iron staining 2.4 to 7.6 m; impure sandstone 7.6 to 8.5 m; Precambrian 8.5 to 9.1 m; 0 to 7.6 m intersection chosen for laboratory study.

Table 3 (cont'd) - Drill core description

Sample			Description
F	whole core	-	0 to 8.8 m fine grain, impure, grey to mottled brown sandstone; substantial percentage of quartz inclusions and veins; some lost core; 0 to 8.8 m intersection chosen for laboratory study.
G*	broken core	-	core from 7 drill holes, 5 holes to 15.2 m, 2 holes to 22.9 m; fine grain, light grey sandstone with pyrite, iron-staining and graphite impurity.

*Note: Because all 7 samples were from one deposit and similar, all were combined to make one large sample for processing and study.

Table 4 - Sieve analysis, washed attrition products

Size (μm)	Sample analyses (wt%)							
	A	B	C_T	C_B	D	E	F	G
+ 425	6.6	6.0	12.3	13.5	14.6	21.0	16.2	14.1
-425, + 300	20.3	36.6	30.3	36.5	29.7	46.9	33.1	27.0
-300, + 200	16.0	27.9	25.0	25.2	18.1	18.9	20.0	18.4
-200, + 150	30.7	20.6	19.9	17.4	22.9	8.5	18.9	19.8
-150, + 100	22.7	8.1	10.3	6.6	11.0	3.9	10.0	14.7
-100	3.7	0.8	2.2	0.8	3.7	0.8	1.5	6.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 5 - Examination of scrubbed attrition products

Sample	Size fraction and description		
	+300 μm	-300, + 150 μm	-150 μm
A	white; rounded to sub-rounded grains; compound grains about 5%; minor attachment/inclusion of dark mineral grains.	similar to +300 μm	similar; trend toward angularity of grains
B	white; rounded to sub-rounded grains, few compound grains; minor dark included and attached grains; minor pyrite, calcite.	similar to +300 μm	similar, increase in number of dark particles and in angularity of grains
C_T	white to gray; rounded to sub-angular grains; 5% mineral impurity: feldspar, dark grains, iron-stained grains, and pyrite; 5% compound grains.	similar to +300 μm	similar; increase in angularity
C_B	white; rounded to sub-rounded grains; few compound grains; minor dark minerals, including pyrite attached to and included in grains.	similar to +300 μm	similar; increase in angularity of grains

Table 5 (cont'd) - Examination of scrubbed attrition products

Sample	Size fraction and description		
	+300 µm	-300, + 150 µm	-150 µm
D	white to grey; rounded to sub-rounded grains; 10% compound grains; attached and included dark grains of minor impurity; some iron-staining; 10% calcite.	similar to +300 µm	similar; trend toward sub-angular to angular grains; high carbonate
E	brown (staining on grains); rounded to sub-angular grains; few compound grains; minor dark inclusions in quartz.	similar to +300 µm	similar; increase in angularity of grains and number of dark particles
F	white to off white; 50/50 rounded/sharply angular grains; few compound grains; 5% impure grains; pyrite and iron staining.	similar to +300 µm	similar; increased angularity
G	light grey; rounded to sub-rounded grains; few compound grains; dark inclusions and attachments; pyrite, iron-staining, graphite impurity.	similar to +300 µm	similar; increased angularity

Table 6 - Mineralogical examination, attrition products

Sample	Comment
A	quartz with traces of calcite and amphibole; most quartz grains are clear and rounded to subrounded with few overgrowths; no inclusions were observed in the quartz nor coatings on the grains; a few opaque, free grains were observed.
B	quartz with minor calcite, pyrite, and possibly amphibole; quartz grains are rounded to subangular with overgrowths on many grains; most grains are liberated and inclusions in grains are rare; contaminants, principally carbonate, are smaller than the quartz grains.
C_T	quartz with trace amounts of K-feldspar and calcite, indications of amphibole and dolomite; quartz grains are rounded to sub-angular; feldspar grains, without twinning or alteration, are not discernable; most of the carbonate grains are liberated and smaller than the quartz grains; some unidentified, opaque grains were observed, mostly attached to quartz grains.
C_B	quartz with trace amounts of carbonate, probably both calcite and dolomite, and amphibole; quartz grains are rounded to sub-angular and many have overgrowths; combined grains and included grains in quartz are rare; most contaminants are in small, free grains; rare opaque grains are usually attached to quartz.
D	quartz with trace amounts of K-feldspar, pyrite, and carbonate, both calcite and dolomite; quartz grains are sub-rounded; a few large aggregates of quartz and carbonate were observed; inclusions were rare; no feldspar was observed.
E	quartz with trace amounts of carbonate, probably both calcite and dolomite, and amphibole; quartz occurs in rounded grains with few inclusions; some grains have thin partial coatings of fine material; most of the contaminants occur as fine, dust-like particles; a few larger, opaque grains and grains of amphibole were observed; inclusions in quartz were rare.

Table 6 (cont'd) - Mineralogical examination, attrition products

Sample	Comment
F	- quartz with minor calcite and trace amounts of feldspar and pyrite; quartz grains are clear and sub-rounded to sharply angular, the latter being especially evident in the finer size ranges.
G	- quartz with trace amounts of feldspar and amphibole; quartz grains were mostly clear, rounded to sub-rounded, with some overgrowths; inclusions were rare; grains with partial coatings of graphite, clay, and ferruginous material were more common than in other samples; rare aggregate of quartz and carbonate were present.

Table 7 - Sample A: chemical analyses of products

Product	Analysis (wt %)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	TiO_2	Cr_2O_3	LOI	Total
Head sample *	96.86	0.69	0.09	0.49	0.03	0.04	n.d.	n.d.	0.65	98.15
Sweco screen products **										
-600 + 125 µm	97.40	0.57	0.09	0.35	0.03	n.d.	n.d.	n.d.	0.64	99.08
-125 µm	n.d.	0.34	0.43	1.69	0.12	n.d.	n.d.	n.d.	2.73	-
Wemco attrition products ***										
-600 + 100 µm	99.80	0.19	0.05	0.23	0.03	n.d.	n.d.	n.d.	0.26	100.56
-100 µm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
Flotation concentrates										
Test 29	99.39	0.098	0.022	0.076	0.008	0.010	n.d.	n.d.	0.31	99.91
Test 30	99.50	0.089	0.024	0.050	0.008	0.013	n.d.	n.d.	0.27	99.95
Test 31	99.48	0.090	0.026	0.046	0.007	0.007	n.d.	n.d.	0.24	99.90
Test 32	99.46	0.094	0.026	0.039	0.007	0.007	n.d.	n.d.	0.26	99.89
Test 33	99.54	0.095	0.026	0.038	0.007	0.011	n.d.	n.d.	0.23	99.95

* Combined -600 µm products from jaw, cone and roll crushers
** Attrition feed, -600 + 125 µm; waste -125 µm
*** Flotation feed, -600 + 100 µm; waste -100 µm

n.d. not determined

Table 7 (cont'd) - Sample B: chemical analyses of products

Product	Analysis (wt %)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	TiO_2	Cr_2O_3	LOI	Total
Head sample *	88.40	0.39	0.13	6.02	0.05	0.04	n.d.	n.d.	4.98	100.01
Sweco screen products **										
-600 + 125 µm	90.90	0.30	0.11	4.90	0.05	n.d.	n.d.	n.d.	4.08	100.34
-125 µm	n.d.	1.29	0.49	26.19	0.17	n.d.	n.d.	n.d.	21.60	-
Wemco attrition products ***										
-600 + 100 µm	94.40	0.12	0.08	3.04	0.03	n.d.	n.d.	n.d.	2.58	100.25
-100 µm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
Flotation concentrates										
Test 14	95.32	0.09	0.05	1.73	0.02	n.d.	n.d.	n.d.	1.31	98.52
Test 15	98.57	0.07	0.029	0.08	0.01	n.d.	n.d.	n.d.	0.23	98.99
Test 16	97.28	0.07	0.038	0.73	0.01	n.d.	n.d.	n.d.	0.64	98.77
Test 17	99.50	0.07	0.030	0.09	0.01	n.d.	n.d.	n.d.	0.23	99.93
Test 44	99.37	0.083	0.034	0.092	0.009	0.046	n.d.	n.d.	0.23	99.86
Test 45	99.59	0.077	0.029	0.055	0.008	0.009	n.d.	n.d.	0.13	99.90
Test 46	98.69	0.067	0.028	0.173	0.008	0.083	n.d.	n.d.	0.35	99.40

* Combined -600 µm products from jaw, cone and roll crushers
** Attrition feed, -600 + 125 µm; waste -125 µm
*** Flotation feed, -600 + 100 µm; waste -100 µm

n.d. not determined

Table 7 (cont'd) - Sample C_T: chemical analyses of product

Product	Analysis (wt %)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	TiO_2	Cr_2O_3	LOI	Total
Head sample *	95.01	1.00	0.48	1.29	0.26	0.15	n.d.	n.d.	0.94	99.13
Sweco screen products **										
-600 + 125 µm	97.57	0.76	0.36	0.60	0.18	n.d.	n.d.	n.d.	0.72	100.19
-125 µm	n.d.	2.61	1.22	2.52	0.59	n.d.	n.d.	n.d.	2.69	-
Wemco attrition products ***										
-600 + 100 µm	97.50	0.54	0.28	0.49	0.14	n.d.	n.d.	n.d.	0.72	99.67
-100 µm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
Flotation concentrates ****										
Test 18	98.48	0.51	0.14	0.21	0.075	0.05	n.d.	n.d.	0.35	99.82
Test 19	98.71	0.49	0.14	0.18	0.075	0.04	n.d.	n.d.	0.32	99.96
Test 51	98.61	0.441	0.144	0.209	0.077	0.033	n.d.	n.d.	0.35	99.86
Test 52	98.82	0.363	0.107	0.104	0.041	0.032	n.d.	n.d.	0.20	99.67
Leached products										
Test 18	n.d.	n.d.	0.067	n.d.	n.d.	n.d.	0.050	0.001	n.d.	-
Test 19	n.d.	n.d.	0.054	n.d.	n.d.	n.d.	0.052	0.001	n.d.	-

* Combined -600 µm products from jaw, cone and roll crushers
** Attrition feed, -600 + 125 µm; waste -125 µm
*** Flotation feed, -600 + 100 µm; waste -100 µm
**** Head sample for leaching, selected samples retain original flotation test numbers

n.d. not determined

Table 7 (cont'd) - Sample C_B: chemical analyses of products

Product	Analysis (wt %)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	TiO_2	Cr_2O_3	LOI	Total
Head sample *	98.09	0.14	0.16	0.65	0.03	0.07	n.d.	n.d.	0.38	99.52
Sweco screen products **										
-600 + 125 µm	99.70	0.09	0.10	0.25	0.02	n.d.	n.d.	n.d.	0.40	100.56
-125 µm	n.d.	0.57	0.62	2.36	0.16	n.d.	n.d.	n.d.	1.89	-
Wemco attrition products ***										
-600 + 100 µm	99.80	0.11	0.10	0.26	0.03	n.d.	n.d.	n.d.	0.32	100.62
-100 µm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
Flotation concentrates ****										
Test 47	99.57	0.074	0.039	0.095	0.030	0.021	n.d.	n.d.	0.18	100.01
Test 48	99.63	0.078	0.037	0.159	0.083	0.017	n.d.	n.d.	0.16	100.16
Test 49	99.54	0.067	0.030	0.063	0.033	0.017	n.d.	n.d.	0.15	99.90
Test 50	99.46	0.067	0.041	0.045	0.015	0.019	n.d.	n.d.	0.15	99.80
Leached products										
Test 47	n.d.	n.d.	0.025	n.d.	n.d.	n.d.	0.015	0.001	n.d.	-
Test 48	n.d.	n.d.	0.024	n.d.	n.d.	n.d.	0.016	0.001	n.d.	-

* Combined -600 µm products from jaw, cone and roll crushers
** Attrition feed, -600 + 125 µm; waste -125 µm
*** Flotation feed, -600 + 100 µm; waste -100 µm
**** Head sample for leaching, selected samples retain original flotation test numbers

n.d. not determined

Table 7 (cont'd) - Sample D : chemical analyses of products

Product	Analysis (wt %)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	TiO_2	Cr_2O_3	LOI	Total
Head sample *	93.70	2.10	0.30	1.95	0.15	0.05	n.d.	n.d.	1.46	99.71
Sweco screen products **										
-600 + 125 µm	95.04	1.81	0.27	1.48	0.13	n.d.	n.d.	n.d.	1.39	100.12
-125 µm	n.d.	5.82	0.90	4.98	0.39	n.d.	n.d.	n.d.	4.33	-
Wemco attrition products ***										
-600 + 100 µm	96.99	0.72	0.11	0.84	0.03	n.d.	n.d.	n.d.	0.73	99.42
-100 µm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
Flotation concentrates ****										
Test 24	98.64	0.62	0.067	0.22	0.026	0.02	n.d.	n.d.	0.31	99.90
Test 25	98.99	0.53	0.048	0.14	0.016	0.01	n.d.	n.d.	0.20	99.93
Test 26	98.78	0.49	0.054	0.18	0.023	0.01	n.d.	n.d.	0.25	99.79
Test 27	98.84	0.55	0.063	0.21	0.018	0.02	n.d.	n.d.	0.25	99.95
Test 28	98.84	0.55	0.054	0.20	0.018	0.01	n.d.	n.d.	0.25	99.92
Test 53	98.68	0.536	0.049	0.201	0.021	0.011	n.d.	n.d.	0.20	99.70
Test 54	99.16	0.433	0.044	0.089	0.015	0.010	n.d.	n.d.	0.15	99.90
Test 55	99.05	0.395	0.048	0.142	0.019	0.065	n.d.	n.d.	0.17	99.89
Leached products										
Test 27	n.d.	n.d.	0.028	n.d.	n.d.	n.d.	0.038	0.001	n.d.	-

* Combined -600 µm products from jaw, cone and roll crushers
** Attrition feed, -600 + 125 µm; waste -125 µm
*** Flotation feed, -600 + 100 µm; waste -100 µm
**** Head sample for leaching, selected samples retain original flotation test numbers

n.d. not determined

Table 7 (cont'd) - Sample E : chemical analyses of products

Product	Analysis (wt %)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	TiO_2	Cr_2O_3	LOI	Total
Head sample *	98.45	0.70	0.13	0.06	0.15	0.01	n.d.	n.d.	0.26	99.66
Sweco screen products **										
-600 + 125 µm	98.47	0.70	0.13	0.03	0.05	n.d.	n.d.	n.d.	0.41	99.79
-125 µm	n.d.	2.89	0.59	0.11	0.20	n.d.	n.d.	n.d.	0.97	-
Wemco attrition products ***										
-600 + 100 µm	99.80	0.14	0.05	0.03	0.01	n.d.	n.d.	n.d.	0.11	100.14
-100 µm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
Flotation concentrates ****										
Test 20	99.67	0.089	0.048	0.015	0.006	0.01	n.d.	n.d.	0.15	99.99
Test 21	99.60	0.109	0.060	0.022	0.010	0.01	n.d.	n.d.	0.20	100.01
Test 22	99.63	0.104	0.055	0.021	0.008	0.01	n.d.	n.d.	0.16	99.99
Test 23	99.63	0.090	0.044	0.012	0.006	0.01	n.d.	n.d.	0.15	99.94
Test 56	99.65	0.089	0.034	0.017	0.008	0.005	n.d.	n.d.	0.10	99.90
Test 57	99.65	0.094	0.039	0.015	0.008	0.006	n.d.	n.d.	0.04	99.85
Test 58	99.59	0.096	0.033	0.014	0.008	0.005	n.d.	n.d.	0.03	99.78
Leached products										
Test 22	n.d.	n.d.	0.028	n.d.	n.d.	n.d.	0.026	0.001	n.d.	-

* Combined -600 µm products from jaw, cone and roll crushers
** Attrition feed, -600 + 125 µm; waste -125 µm
*** Flotation feed, -600 + 100 µm; waste -100 µm
**** Head sample for leaching, selected samples retain original flotation test numbers

n.d. not determined

Table 7 (cont'd) - Sample F : chemical analyses of products

Product	Analysis (wt %)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	TiO_2	Cr_2O_3	LOI	Total
Head sample *	95.94	1.06	0.30	1.20	0.06	0.05	n.d.	n.d.	0.98	99.59
Sweco screen products **										
-600 + 125 µm	98.40	0.85	0.21	0.87	0.05	n.d.	n.d.	n.d.	0.79	101.17
-125 µm	n.d.	0.30	1.13	3.33	0.18	n.d.	n.d.	n.d.	3.02	-
Wemco attrition products ***										
-600 + 100 µm	99.70	0.23	0.13	0.42	0.03	n.d.	n.d.	n.d.	0.41	100.92
-100 µm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
Flotation concentrates ****										
Test 34	99.34	0.152	0.043	0.080	0.008	0.008	n.d.	n.d.	0.30	99.93
Test 35	99.51	0.137	0.039	0.034	0.007	0.007	n.d.	n.d.	0.23	99.96
Test 36	99.50	0.141	0.039	0.035	0.007	0.005	n.d.	n.d.	0.22	99.95
Test 37	99.37	0.096	0.031	0.036	0.005	0.005	n.d.	n.d.	0.22	99.76
Test 38	99.40	0.074	0.037	0.043	0.005	0.007	n.d.	n.d.	0.21	99.78
Test 61	99.56	0.145	0.038	0.046	0.010	0.007	n.d.	n.d.	0.20	100.01
Test 62	99.70	0.323	0.093	0.207	0.030	0.009	n.d.	n.d.	0.18	100.54
Leached products										
Test 35	n.d.	n.d.	0.023	n.d.	n.d.	n.d.	0.026	0.001	n.d.	-
Test 36	n.d.	n.d.	0.028	n.d.	n.d.	n.d.	0.031	0.001	n.d.	-

* Combined -600 µm products from jaw, cone and roll crushers
** Attrition feed, -600 + 125 µm; waste -125 µm
*** Flotation feed, -600 + 100 µm; waste -100 µm
**** Head sample for leaching, selected samples retain original flotation test numbers

n.d. not determined

Table 7 (cont'd) - Sample G : chemical analyses of products

Product	Analysis (wt %)										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	TiO_2	Cr_2O_3	C	LOI	Total
Head sample *	88.50	1.52	0.65	4.45	0.29	0.16	n.d.	n.d.	1.22	3.71	100.50
Sweco screen products **											
-600 + 125 µm	91.78	1.19	0.56	3.22	0.23	n.d.	n.d.	n.d.	1.06	2.75	100.74
-125 µm	n.d.	0.32	1.50	10.23	0.63	n.d.	n.d.	n.d.	3.75	9.71	-
Wemco attrition products ***											
-600 + 100 µm	93.90	0.50	0.33	2.25	0.15	n.d.	n.d.	n.d.	0.52	2.00	99.65
-100 µm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
Flotation concentrates ****											
Test 39	97.24	0.300	0.156	0.652	0.083	0.150	n.d.	n.d.	0.13	0.64	99.35
Test 40	99.02	0.257	0.060	0.118	0.018	0.015	n.d.	n.d.	0.07	0.31	99.87
Test 41	98.53	0.329	0.110	0.409	0.051	0.015	n.d.	n.d.	0.12	0.55	100.11
Test 42	99.11	0.244	0.061	0.125	0.018	0.017	n.d.	n.d.	0.07	0.31	99.96
Test 43	98.95	0.189	0.063	0.091	0.018	0.015	n.d.	n.d.	0.06	0.28	99.67
Test 59	99.10	0.181	0.070	0.123	0.021	0.023	n.d.	n.d.	0.11	0.29	99.92
Test 60	99.11	0.098	0.043	0.039	0.008	0.027	n.d.	n.d.	0.11	0.28	99.72
Test 63	99.36	0.336	0.100	0.149	0.026	0.014	n.d.	n.d.	0.08	0.24	100.31
Leached products											
Test 40	n.d.	n.d.	0.027	n.d.	n.d.	n.d.	0.030	0.001	n.d.	n.d.	-
Test 42	n.d.	n.d.	0.026	n.d.	n.d.	n.d.	0.032	0.001	n.d.	n.d.	-

* Combined -600 µm products from jaw, cone and roll crushers
** Attrition feed, -600 + 125 µm; waste -125 µm
*** Flotation feed, -600 + 100 µm; waste -100 µm
**** Head sample for leaching, selected samples retain original flotation test numbers

n.d. not determined

Table 8 - Flotation reagent consumption (kg/t)

Sample A

Test no.	Sulphide flotation					Calcite flotation					Fe Oxide/Feldspar flotation						
	% Wt	pH	H_2SO_4	Eth. Xan.	D. 250	% Wt	pH	H_2SO_4	Oleic	D. 250	% Wt	pH	H_2SO_4	Arm. T	Armac C	Aero 840	D. 250
29	0.04	6.0	0.18	0.07	0.06	-	-	-	-	-	0.3	2.5-3.2	2.62	0.37	-	-	0.13
30	0.1	6.0	0.37	0.07	0.06	0.5	6.9	-	0.27	0.13	0.7	2.5-3.0	0.91	0.37	-	-	0.17
31	-	-	-	-		0.3	7.0	0.09	0.36	0.17	1.5	2.5-2.8	1.29	0.38	-	-	0.13
32	0.4	6.0	0.18	0.05	0.06	1.1	7.0		0.26	0.13	0.6	2.5-2.9	1.28	-	0.37	-	-
33	0.05	6.0	0.18	0.05	0.06	0.5	7.5	0.02	0.26	0.17	0.2	2.5-3.0	1.01	-	-	0.37	0.17

Sample B

Test no.	Sulphide flotation					Calcite flotation					Fe Oxide/Feldspar flotation							
	% Wt	pH	H_2SO_4	Eth. Xan.	D. 250	% Wt	pH	H_2SO_4	Oleic	D. 250	% Wt	pH	H_2SO_4	Arm. T	Arm. C	A. 840	TDO	D. 250
14	0.20	6.0	1.85	0.09	0.06	-	-	-	-	-	4.29	2.5-3.5	25.15	0.23	-	-	-	-
15	0.15	6.0	1.55	0.07	0.04	7.91	7.0	0.18	0.42	0.14	0.32	2.3-3.2	2.09	0.36	-	-	-	0.12
16	3.32	6.0	1.44	0.07	0.04	5.48	7.0	0.04	0.22	0.10	10.96	2.7-3.5	2.25	0.25	-	-	-	-
17	1.50	6.0	1.11	0.07	0.04	7.41	7.9	-	0.13	0.06	0.75	2.5-3.2	1.57	-	0.24	-	-	-
44	0.20	6.0	2.05	0.07	0.06	7.10	7.0	0.71	0.31	0.13	0.40	2.5	9.77	-	-	0.25	-	-
45	0.20	6.0	1.70	0.07	0.06	5.10	7.0	0.22	0.49	0.13	2.40	2.5-2.8	7.45	0.25	-	-	-	0.06
46	0.20	6.0	1.62	0.07	0.04	5.60	7.0	0.27	0.88	0.10	1.50	2.1	14.75	-	-	-	0.24	0.06

Table 8 (cont'd) - Flotation reagent consumption (kg/t)

Sample C_T

Test no.	Sulphide Flotation					Calcite Flotation					Fe Oxide/Feldspar flotation						
	% Wt	pH	H_2SO_4	Eth. Xan.	D. 250	% Wt	pH	H_2SO_4	Oleic	D. 250	% Wt	pH	H_2SO_4	Arm. T	A. 840	TDO	D. 250
18	1.4	6.0	0.80	0.08	0.04	-	-	-	-	-	0.8	2.5-3.2	5.81	0.75	-	-	0.08
19*	1.4	6.0	0.45	0.08	0.06	1.2	7.0	-	0.22	0.09	0.2	2.5-3.2	1.98	0.38	-	-	0.09
51	1.4	6.0	0.39	0.11	0.05	1.1	7.0	0.06	0.40	0.10	0.2	2.5-2.8	2.51	0.28	-	-	0.10
52	1.4	6.0	0.31	0.08	0.05	0.8	7.0	0.08	0.40	0.09	2.1	2.1-2.5	4.87	-	-	0.28	0.09
51**											0.8	5.0	0.27	-	0.28	-	0.05
52**											0.9	5.0	0.22	-	0.28	-	0.05

* Deslimed at 100 µm prior to sulphide flotation
** A petroleum sulphonate flotation stage was conducted before the feldspar flotation stage

Sample C_B

Test no.	Sulphide flotation					Calcite flotation					Fe Oxide/Feldspar flotation							
	% Wt	pH	H_2SO_4	Eth. Xan.	D. 250	% Wt	pH	H_2SO_4	Oleic	D. 250	% Wt	pH	H_2SO_4	Arm. T	Arm C	A. 840	TDO	D. 250
47	0.5	6.0	0.37	0.10	0.06	0.3	7.0	0.05	0.61	0.12	0.1	2.5-2.8	2.21	0.34	-	-	-	0.09
48	0.7	6.0	0.42	0.10	0.06	1.2	7.0	0.05	0.61	0.12	0.7	2.5-2.8	1.07	-	-	0.34	-	0.09
49	0.6	6.0	0.50	0.10	0.06	1.5	7.0	0.03	0.61	0.12	1.4	2.1-2.4	1.67	-	-	-	0.34	0.12
50	0.8	6.0	0.35	0.10	0.06	1.6	7.0	0.10	0.73	0.12	0.3	2.5-2.8	1.02	-	0.34	-	-	-

Sample D

Table 8 (cont'd) - Flotation reagent consumption (kg/t)

Test no.	Sulphide flotation					Calcite flotation							Fe Oxide/Feldspar flotation								
	% Wt	pH	H_2SO_4	Eth. Xan.	D. 250	% Wt	pH	H_2SO_4	Oleic	A. 840	D. 250	MIBC	% Wt	pH	H_2SO_4	Arm. T	Arm. C	A. 840	TDO	D. 250	MIBC	Kero
24	0.2	8.9	-	0.09	0.08	-	-	-	-	-	-	-	0.9	2.5-3.2	7.90	0.45	-	-	-	0.15		-
25	0.3	6.0	0.68	0.09	0.08	3.6	7.6	-	0.39	-	0.16	-	0.4	2.5-3.2	1.90	0.46	-	-	-	0.18		-
26	0.6	6.0	1.25	0.09	0.08	2.2	7.2	-	0.53	-	0.15	-	1.4	2.5-3.2	2.16	-	0.59					
27						2.9	7.5	0.05	0.39	-	0.16	-	0.5	2.5-3.2	2.71	0.47	-	-	-	0.21		-
28	0.4	6.0	0.45	0.09	0.08	2.2	7.5	0.05	0.38	-	0.15	-	0.2	2.5-3.2	2.59	-	-	0.45	-	0.21		-
53	0.4	6.0	0.39	0.09	0.05	1.2	3.5-4.0	2.36	0.84	0.31	0.16	-	0.9	2.5-2.8	2.79	0.31	-	-	-	0.11		0.20
54**	1.0	6.0	0.41	0.09	0.05	3.7	7.0	0.07	0.83	-	0.05	-	0.4	3.5-4.0	0.54	-	-	0.31	-	0.08		-
54													1.1	2.1-2.5	1.99	-	-	-	0.31	0.13		-
55	0.3	6.0	0.33	0.09	0.05	2.5	7.0	0.07	0.80	-	-	0.11	2.6	2.5-2.8	1.18	-	0.30	-	-	-	0.04	0.19

** A petroleum sulphonate flotation stage was conducted before the feldspar flotation stage.

Sample E

Test no.	Sulphide flotation					Fe Oxide/Feldspar flotation								
	% Wt	pH	H_2SO_4	Eth. Xan.	D. 250	% Wt	pH	H_2SO_4	Arm. T	Arm. C	A. 840	TDO	Kero	D. 250
20	0.02	8.0	-	0.10	0.06	0.32	2.5-3.0	0.33	0.37	-	-	-	-	0.06
21	0.02	6.0	0.04	0.05	0.06	0.13	2.5-2.9	0.25	0.37	-	-	-	-	0.13
22	-	-	-	-	-	0.62	2.5-3.2	0.23	-	0.37	-	-	-	0.04
23	-	-	-	-	-	0.16	2.5-2.9	0.21	-	-	0.36	-	-	0.14
56**	-	-	-	-	-	0.10	4.0	0.13	-	-	0.25	-	0.24	0.13
56						2.90	2.5-2.8	0.37	0.25	-	-	-	0.16	0.13
57	-	-	-	-	-	1.30	2.1-2.5	1.28	-	-	0.25	0.25	-	0.09
58	-	-	-	-	-	1.70	2.5-2.8	0.49	-	0.25	0.25	-	-	-

** A petroleum sulphonate flotation stage was conducted before the feldspar flotation stage.

Table 8 (cont'd) - Flotation reagent consumption (kg/t)

Sample F

Test no.	Sulphide flotation					Calcite flotation					Fe Oxide/Feldspar flotation							
	% Wt	pH	H_2SO_4	Eth. Xan.	D. 250	% Wt	pH	H_2SO_4	Oleic	D. 250	% Wt	pH	H_2SO_4	Arm. T	Arm. C	A. 840	TDO	D. 250
34	0.3	6.0	0.47	0.09	0.10	–	–	–	–	–	0.5	2.5-3.0	4.70	0.44	–	–	–	0.15
35*	0.3	6.0	0.51	0.09	0.10	1.0	7.0	0.05	0.38	0.15	0.2	2.5-3.0	0.93	0.45	–	–	–	0.21
36*	0.3	6.0	0.85	0.09	0.10	0.1	7.0	0.24	0.37	0.15	1.1	2.5-2.7	1.96	–	0.35	–	–	
37*	0.3	6.0	0.46	0.09	0.10	0.6	7.2	0.04	0.37	0.16	0.6	2.5-3.0	0.85	–	–	0.44	–	0.20
38*	0.2	6.0	0.37	0.09	0.10	0.4	7.0	0.22	0.38	0.15	1.1	2.5-2.8	1.98	–	–	–	0.45	0.18
61*	0.4	6.0	0.44	0.09	0.11	1.0	7.0	0.05	0.45	0.19	3.8	2.3-2.5	0.79	–	–	0.63	–	0.19
62*	0.4	6.0	0.35	0.09	0.11	0.8	7.0	0.09	0.45	0.19	44.5	2.1-2.3	1.87	–	–	–	0.63	0.11

* Deslimed at 100μm.

Sample G

Test no.	Graphite/sulphide flotation							Calcite flotation					Fe Oxide/Feldspar flotation							
	% Wt	pH	H_2SO_4	Eth. Xan.	Kero	MIBC	D. 250	% Wt	pH	H_2SO_4	Oleic	MIBC	% Wt	pH	H_2SO_4	Arm. T	Arm. C	A. 840	TDO	D. 250	MIBC
39	0.9	6.0	2.45	0.07	0.72	0.15	–	–	–	–	–	–	5.6	2.5-2.8	31.14	0.34	–	–	–	–	–
40	2.2	8.8	–	0.08	0.89	0.22	–	11.9	6.9	1.01	0.76	0.08	2.0	2.5-2.9	2.33	0.42	–	–	–	0.19	–
41***	1.1	6.0	2.34	0.09	–	–	0.10	4.7	7.0	1.00	0.77	0.08	0.8	2.5-2.9	6.44	–	0.43	–	–	–	–
41	1.0	8.0	–	–	0.90	0.23	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
42***	1.1	8.9	–	–	0.81	0.19	–	11.0	7.0	0.11	0.69	0.11	0.3	2.5-2.9	2.80	–	–	0.39	–	0.17	–
42	1.2	6.0	3.89	0.08	–	–	0.09	–	–	–	–	–	–	–	–	–	–	–	–	–	–
43	1.8	8.8	–	0.08	0.80	0.20	–	11.4	7.0	1.20	0.69	0.11	2.7	2.1-2.5	3.86	–	–	–	0.38	0.17	–
59	1.4	9.0	–	0.05	0.40	0.13	–	12.9	7.0	0.80	0.81	0.11	1.4	2.3-3.0	1.22	–	–	0.50	–	–	–
60	0.9	9.0	–	0.05	0.38	0.12	–	15.9	7.0	0.37	0.78	0.10	2.5	2.3-2.5	0.51	0.48	–	–	–	–	0.04
63	1.6	9.0	–	0.05	0.42	0.14	–	15.4	7.0	0.30	0.48	0.08	22.9	2.1-2.3	2.82	–	–	–	0.54	–	0.04

***Separate sulphide and graphite flotation: Test 41-Sulphide followed by graphite flotation
Test 42-Graphite followed by sulphide flotation

Table 9 - Conditioning and flotation times

Sample no.	Test no.	Sulphide flotation		Calcite flotation			Sulphonate flotation					Fe Oxide/Feldspar flotation				
		Cond* min	Float min	Cond** min	Cond* min	Float min	Cond** min	Cond*** min	Float min	Cond*	Float min	Cond** min	Cond*** min	Float min	Cond* min	Float min
A	29	6	5	–	–	–	–	–	–	–	–	–	4	4	3	2
	30	6	5	–	8	5	–	–	–	–	–	–	4	4	3	2
	31	–	–	–	8	5	–	–	–	–	–	–	4	4	–	–
	32	3	3	–	5	6	–	–	–	–	–	–	4	4	3	2
	33	5	3	–	5	5	–	4	4	3	2	–	–	–	–	–
B	14	10	6	–	–	–	–	–	–	–	–	–	4	5	–	–
	15	6	4	–	8	4	–	–	–	–	–	–	4	4	3	2
	16	7	4	–	5	3	–	–	–	–	–	–	4	4	–	–
	17	6	4	–	4	3	–	–	–	–	–	–	4	4	–	–
	44	5	4	–	8	5	4	4	3	–	–	–	–	–	–	–
	45	5	4	–	5	6	–	–	–	–	–	4	4	3	–	–
	46	5	3	–	5	6	–	–	–	–	–	4	4	5	–	–
C_T	18	6	5	–	–	–	–	–	–	–	–	–	4	4	11	12
	19	6	5	–	7	5	–	–	–	–	–	–	4	4	4	3
	51	4	3	–	5	4	–	–	–	4	3	4	4	4	–	–
	52	5	3	–	5	4	–	–	–	4	3	4	4	4	–	–
C_B	47	5	3	–	5	3.5	–	–	–	–	–	4	4	4	–	–
	48	5	3	–	5	3.5	4	4	4	–	–	–	–	–	–	–
	49	5	3	–	5	3.5	–	–	–	–	–	4	4	4	–	–
	50	5	3	–	5	4	–	–	–	–	–	4	4	4	–	–
D	24	6	4	–	–	–	–	–	–	–	–	–	4	4	3	4
	25	6	4	–	8	5	–	–	–	–	–	–	4	4	3	4
	26	6	4	–	10	8	–	–	–	–	–	–	4	4	3	4
	27	–	–	–	8	5	–	–	–	–	–	–	4	4	3	2
	28	6	4	–	8	5	–	4	4	3	2	–	–	–	–	–
	53	5	3	4	4***	10	–	–	–	–	–	4	4	4	–	–
	54	5	3	–	4	4	4	4	5	–	–	4	4	4	–	–
	55	5	3	–	6***	5	–	–	–	–	–	–	4	4	–	–

*Conditioning and flotation were conducted at approximately 30% solids
**Conditioning with pH modifier only
***Conditioning was conducted at 50% solids and flotation at 30% solids

Table 9 (cont'd) - Conditioning and flotation times

Sample no.	Test no.	Sulphide flotation		Graphite flotation		Calcite flotation			Sulphonate flotation					Fe Oxide/feldspar flotation				
		Cond* min	Float min	Cond* min	Float min	Cond** min	Cond* min	Float min	Cond** min	Cond*** min	Float min	Cond* min	Float min	Cond** min	Cond*** min	Float min	Cond* min	Float min
E	20	6	4	–	–	–	–	–	–	–	–	–	–	–	4	4	4	3
	21	3	3	–	–	–	–	–	–	–	–	–	–	–	4	5	3	3
	22	–	–	–	–	–	–	–	–	–	–	–	–	–	4	4	3	2
	23	–	–	–	–	–	–	–	–	–	–	–	–	–	5	4	3	3
	56	–	–	–	–	–	–	–	4	5	4	–	–	4	4	4	–	–
	57	–	–	–	–	–	–	–	–	–	–	–	–	4	5	4	–	–
	58	–	–	–	–	–	–	–	–	–	–	–	–	4	5	4	–	–
F	34	8	6.5	–	–	–	–	–	–	–	–	–	–	–	4	4	3	2
	35	8	6	–	–	–	8	5	–	–	–	–	–	–	4	3	3	2
	36	8	6	–	–	–	8	5	–	–	–	–	–	–	4	3	3	2
	37	8	6	–	–	–	8	5	–	4	4	3	2	–	–	–	–	–
	38	8	6	–	–	–	8	5	–	–	–	–	–	–	4	3	3	2
	61	5	5	–	–	–	5	5	–	–	–	–	–	–	5	5	–	–
	62	5	5	–	–	–	5	4	–	–	–	–	–	–	4	3	–	–
G	39	8	6	–	–	–	–	–	–	–	–	–	–	–	4	4	3	4
	40****	8	8	–	–	–	9	8	–	–	–	–	–	–	4	4	3	3
	41	8	6	8	8	–	9	8	–	–	–	–	–	–	4	4	3	3
	42	8	6	8	8	–	9	10	–	4	4	3	3	–	–	–	–	–
	43****	8	8	–	–	–	9	10	–	–	–	–	–	–	4	4	3	3
	59****	5	4	–	–	–	10	10	–	4	4	–	–	–	–	–	–	–
	60****	5	4	–	–	–	10	10	–	–	–	–	–	–	4	4	–	–
	63	5	4	–	–	–	5	5	–	–	–	–	–	–	4	3	–	–

*Conditioning and flotation were conducted at approximately 30% solids
**Conditioning with pH modifier only
***Conditioning was conducted at 50% solids and flotation at 30% solids
****Combined graphite and sulphide flotation

Table 10 - Collector(s) employed in achieving optimum results

Sample	Test no.	Collector(s)
A	30	Armac T
B	45	Armac T
C_T	52	Aerofloat 840 followed by Duomeen TDO
C_B	49	Duomeen TDO
D	54	Aerofloat 840 followed by Duomeen TDO
E	56	Aerofloat 840 followed by Armac T
F	38	Duomeen TDO
G	60	Armac T

Table 11 - Foundry test results

Sample	Moist	Mould	Perm	Gr. comp.	Gr. tensile	AFS no.
A	3.4	74	109	6.3	10.3	65.1
B	2.8	75	175	6.9	12.9	51.4
C_T		insufficient sample				53.9
C_B	3.6	74	238	7.6	12.0	45.9
D	3.3	73	155	6.1	11.7	50.3
E	3.3	76	297	5.7	10.7	39.9
F	3.4	75	167	6.6	12.7	54.0
G	3.3	73	146	7.3	12.6	55.1

Table 12 - Product recoveries (wt %)

Product	Sample A			Sample B			Sample C_T			Sample C_B		
	Actual	Net	Calculated*	Actual	Net	Calculated*	Actual	Net	Calculated*	Actual	Net	Calculated*
Primary crushing (jaw, cone, rolls)												
Feed, core samples	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Products +600 µm	4.2	4.2	-	5.1	5.1	-	7.9	7.9	-	8.2	8.2	-
-600 µm	95.8	95.8	100.0	94.9	94.9	100.0	92.1	92.1	100.0	91.8	91.8	100.0
Sweco screening												
Feed -600 µm from crushing	100.0	95.8	100.0	100.0	94.9	100.0	100.0	92.1	100.0	100.0	91.8	100.0
Products -600 + 125 µm	93.9	90.0	93.9	94.2	89.4	94.2	89.6	82.5	89.6	93.2	85.6	93.2
-125 µm	6.1	5.8	6.1	5.8	5.5	5.8	10.4	9.6	10.4	6.8	6.2	6.8
Simpson Muller												
Feed -600 + 125 µm from Sweco	100.0	90.0	93.9	100.0	89.4	94.2	100.0	82.5	89.6	100.0	85.6	93.2
Product -600 µm	100.0	90.0	93.9	100.0	89.4	94.2	100.0	82.5	89.6	100.0	85.6	93.2
Wemco Scrubber												
Feed -600 µm from Simpson	100.0	90.0	93.9	100.0	89.4	94.2	100.0	82.5	89.6	100.0	85.6	93.2
Products -600 +100 µm	95.9	86.3	90.0	92.5	82.7	87.1	96.2	79.4	86.2	98.7	84.5	92.0
-100 µm	4.1	3.7	3.9	7.5	6.7	7.1	3.8	3.1	3.4	1.3	1.1	1.2
Flotation **												
Feed -600 + 100 µm from Wemco	100.0	86.3	90.0	100.0	82.7	87.1	100.0	79.4	86.2	100.0	84.5	92.0
Products: Concentrate	1.2	1.0	1.1	7.5	6.2	6.5	3.7	2.4	3.2	2.4	2.0	2.2
Tailings ***	98.8	85.3	88.9	92.5	76.5	80.6	96.3	76.5	83.0	97.6	82.5	89.8

* These calculations assume a 100% recovery of -600 µm sand from crushing; the +600 µm material would normally be recycled and recrushed.

** Average figures were used in calculating product recovery for flotation products

*** As reverse flotation was employed, the quartz concentrate is reported as flotation tailings.

Table 12 (cont'd) - Product recoveries (wt%)

Product	Sample D			Sample E			Sample F			Sample G		
	Actual	Net	Calculated*	Actual	Net	Calculated*	Actual	Net	Calculated*	Actual	Net	Calculated*
Primary crushing (jaw, cone, rolls)												
Feed, core samples	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Products +600 µm	11.8	11.8	-	10.2	10.2	-	24.2	24.2	-	16.7	16.7	-
-600 µm	88.2	88.2	100.0	89.8	89.8	100.0	75.8	75.8	100.0	83.3	83.3	100.0
Sweco screening												
Feed -600 µm from crushing	100.0	88.2	100.0	100.0	89.8	100.0	100.0	73.8	100.0	100.0	83.3	100.0
Products -600 + 125 µm	9.8	81.0	91.8	95.6	85.8	95.5	91.4	67.5	91.5	87.8	73.1	87.8
-125 µm	8.2	7.2	8.2	9.9	9.0	4.5	8.6	6.3	8.5	12.2	10.2	12.2
Simpson Muller												
Feed -600 + 125 µm from Sweco	100.0	81.0	91.8	100.0	85.8	95.5	100.0	67.5	91.5	100.0	73.1	87.8
Product -600 µm	100.0	81.0	91.8	100.0	85.8	95.5	100.0	67.5	91.5	100.0	73.1	87.8
Wemco Scrubber												
Feed -600 µm from Simpson	100.0	81.0	91.8	100.0	90.7	95.5	100.0	67.5	91.5	100.0	73.1	87.8
Products -600 +100 µm	89.4	72.4	82.1	99.9	90.6	95.4	82.6	55.8	75.6	95.5	69.8	83.8
-100 µm	10.6	8.6	9.7	0.1	0.1	0.1	17.4	11.7	15.9	4.5	3.3	9.0
Flotation **												
Feed -600 + 100 µm from Wemco	100.0	72.4	82.1	100.0	90.6	95.4	100.0	55.8	75.6	100.0	69.8	83.8
Products: Concentrate	3.7	2.7	3.0	0.7	0.6	0.7	2.3	1.3	1.7	13.5	9.4	11.3
Tailings ***	96.3	69.7	79.1	99.3	90.0	94.7	97.7	54.5	73.9	86.5	60.4	72.5

* These calculations assume a 100% recovery of -600 µm sand from the crushing; the +600 µm material would normally be recycled and recrushed.

** Average figures were used in calculating product recovery for flotation products.

*** As reverse flotation was employed the quartz concentrate is reported as flotation tailings.